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A STUDY OF THE X-RAY EMISSION FROM THREE RADIO PULSARS

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Annual Report

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The subject grant covers ROSAT studies of isolated pulsars as well as the supernova remnant W28. In addition to the ROSAT HRI observations of W28, we have obtained ASCA observations of this remnant. By combining the high resolution map produced by the HRI with the imaging and spectral information provided by the ASCA data, we are investigating models for the global evolutionary properties of the remnant.

Earlier high resolution studies of W28 with the *Einstein* Observatory revealed a centrally-located point source, suggesting the possibility of an associated neutron star. Our HRI observation reveals no such source3, however, nor is a corresponding source seen in the ASCA data. This apparent variability in flux suggests that the source is a background object rather than a neutron star.

Continued efforts to model the X-ray brightness distribution for W28 are underway. Preliminary results suggest difficulties with interpretations of the center-brightened diffuse profile based upon either evaporating cloud models are models for radiative phase evolution. The results were reported at the recent Minnesota Astronomy Centennial workshop; a copy of the abstract is attached.

Minnesota Astronomy Centennial
10^{51} Ergs: The Evolution of Shell SNRs
Poster Session

Session 1: Very Young Remnants

1.01

Laboratory Simulation of Hydrodynamic Phenomena in Supernova Remnants

R. Paul Drake (U. Michigan), S. Gail Glendinning (Lawrence Livermore National Lab), Kent Estabrook (LLNL), Richard McCray (U. Colorado), Bruce Remington (LLNL), A.M. Rubenchik (U.C. Davis), E. Liang (Rice) R. London (LLNL), R.J. Wallace (LLNL), J. Kane (U. Arizona)

We are developing experiments[1] using the Nova laser to investigate hydrodynamic phenomena relevant to supernova explosions[2] and to SNRs. Our aim is to provide tests of the computational models now used to interpret the astrophysical observations, and also to provide data that suggests directions for their improvement. In experiments relevant to Very Young SNRs, we are investigating the evolution of the hydrodynamic assembly formed by the collision of high-Mach-number ejecta with ambient plasma. This is motivated by modeling of SN1987A. The aim is to improve the predictions of the impending collision between such an assembly and the nebular ring. Further experiments will produce radiative hydrodynamic systems. These will be relevant to remnant formation in the more typical Type II SN having a denser circumstellar medium. The SNR experiments and their connections to modeling will be discussed. (Work supported by the US Department of Energy.) [1] B.A. Remington et al., in press, Phys. Plasmas (May, 1997) [2] J. Kane et al., in press, Ap. J. Lett. (March-April, 1997).

1.02

The Nature of Recent Radio Supernovae

Schuyler D. Van Dyk (Visiting scientist at UCLA), Marcos J. Montes (NRC/NRL), Richard A. Sramek (NRAO/VLA), Kurt W. Weiler (NRL), Nino Panagia (ESA/STScI)

The radio emission from supernovae (SNe) is nonthermal synchrotron radiation of high brightness temperature, with a "turn-on" delay at longer wavelengths, power-law decline after maximum with index β, and spectral index α asymptotically decreasing with time to a final, optically thin value. Radio supernovae (RSNe) are best described by the Chevalier (1982) "mini-shell" model,with modifications by Weiler et al. (1990). RSNe observations provide a valuable probe of the SN circumstellar environment and progenitor system. We present a progress report on the nature of the recent Type IIb SNe 1993J and 1996cb, and of the Type Ic SN 1994I.

1.03

Radio Emission from Supernovae

S.D. Van Dyk (UCLA), M.J. Montes (NRC/NRL), K.W. Weiler (NRL), R.A. Sramek (NRAO-VLA), N. Panagia (STScI/ESA), R. Park (TJHS)

Radio supernovae (RSNe) are an excellent means of probing the circumstellar matter around, and therefore the winds from, supernova (SN) progenitor stars or stellar systems. The observed radio synchrotron emission is best described by a modified Chevalier model which involves the generation of relativistic electrons and enhanced magnetic field through the SN shock interacting with a relatively high-density circumstellar envelope, presumed to have been established through mass loss in the late stages of stellar evolution.

Since the detection of SN 1979C in 1980, extensive data have been collected and analyzed for two dozen RSNe.

loss times, and a power law spectrum with a spectral index of alpha = 1.3 +- 0.2, we conclude that the hard X-ray feature is synchrotron radiation from a site of enhanced particle acceleration. Evidence against a plerion includes a lack of observed periodicity (the pulsed fraction upper limit is 33spectral similarity with another more extended hard region, the location of the source outside the 95source, the fact that it is nestled in a bend in the molecular cloud ring with which IC 443 is interacting, and the requirement of an extremely high transverse velocity (¿ 5,000 km/s). We conclude that the anomalous feature is most likely tracing enhanced particle acceleration by shocks that are formed as the supernova blast wave impacts the ring of molecular clouds.

4.19

A ROSAT Study of Centrally-Condensed X-ray Supernova Remnants

Knox S. Long (STScI), Willaim P. Blair (JHU), P. Frank Winkler (Middlebury College)

The ROSAT PSPC has been used to observe four supernova remnants, HB 3, HB 9, HB 21, and W 63, that are members of the class of remnants with shell-like radio and/or optical morphologies and centrally condensed X-ray morphologies. The ROSAT X-ray images of all of the SNRs show considerable internal structure. In the cases of HB 3 and HB 9 the X-ray emission almost fills the region within the radio shell. The emission from HB 21 and W 63 does not fill the radio shell, but this may simply be due to the fact that these two SNRs are fainter and the surface brightness of the outer portions of the SNRs falls below our surface brightness limit.

The ROSAT spectra of all four remnants are similar, peaking sharply at about 0.9 keV, and arise most likely from thermal X-ray emission from normal abundance plasmas with effective temperatures in the range 0.2 - 0.7 keV. The X-ray observations are supplemented by new HA and [S II] images obtained for this study. In general, there is a poor correlation between the X-ray and radio or optical structures in these SNRs. The thermal energy content of the hot gas we detect in HB3 and HB9 is close to that expected of a typical SN explosion, but the energy content of the hot gas in HB21 and W63 is far less, consistent with the suggestion that these two SNRs are well into the radiative phase of their evolution.

Session 5: Thermal-Filled Composite Remnants

5.01

ASCA Observations of Two Composite SNRs: VRO42.05.01 and 3C400.2

David Burrows (Penn State U.), Zhiyu Guo (Goddard Space Flight Center)

We present ASCA observations of two old composite SNRs: VRO42.05.01 and 3C400.2. Both remnants have a center-filled X-ray morphology which has been interpreted on the basis of ROSAT PSPC data as consistent with the White and Long model of evaporation of embedded cloudlets. The X-ray spectra of the two differ dramatically. VRO42.05.01 has a nearly featureless spectrum, consistent with very low abundances of Mg and Si. 3C400.2 has strong Si and Mg lines. We discuss our spectral fitting results and possible explanations for the spectral differences.

5.02

Center-Filled X-ray Morphology in SNRs

Patrick Slane (Harvard-Smithsonian Center for Astrophysics), J.P. Hughes (Rutgers), R. Petre (NASA/GSFC), J.-H. Rho (Saclay)

A distinct subset of moderate age remnants are characterized by an X-ray morphology which is centrally brightened, in complete contrast to the limb-brightened radio profile. In some cases (e.g. CTA 1, MSH 11-62), recent observations have shown that the central emission is nonthermal in nature, presumably associated with a pulsar-driven synchrotron nebula. For others, however, the central emission is decidedly thermal. The evolutionary characteristics which have led to such an observed profile are not well understood. One possible scenario is that the shells in these remnants have recently gone radiative, thus leaving only the hot interior to persist in X-rays. Another suggestion is that the central emission measure has been enhanced by the presence of cool clouds left relatively intact after the passage of the blast wave to slowly evaporate in the hot remnant interior. We have applied models for these scenarios to the X-ray brightness and temperature profiles for the center-filled SNRs MSH 11-61A and W28. Here we report on the results of this study and discuss the age, energy, and density characteristics implied by the models for these remnants.

5.03

Excitation and disruption of a molecular cloud by the 3C391 supernova remnant

Rho, J.-H. (CEA-Saclay, France) and Reach, W. T. (IAS-Orsay, France)

The interactions with clouds, which possibly provide evaporating clouds, are being confirmed in infrared and millimeter wavelengthes for 3C391 and W44. The brightness of the [OI] 63 μm line, an energy tracer, was $\sim 0.3 - 1.4 \times 10^{-3}$ erg cm^{-2} sr^{-1}, detected in the 20 positions observed toward both remnants. The lines of 3C391 and W44 are brightest strongly peaked, at the edges of the remnants, which brightness suggest pre-shock densities $> 10^3$ cm^{-3} and ram pressures of order 10^{-7} dyne cm^{-2}, compared with theoretical models (e.g. Hollenbach & Mckee 1989), as might occur for a supernova blast wave interacting with a molecular cloud. Continuum emission toward the remnant, expected from dust heated by the shock is detected. The radiative energy loss infers that the remnants are in Sedov Stage, rather than a radiative phase. We have also mapped a molecular cloud, into which the shock front of the SNR 3C391 is currently impacting, in three lines of CS simultaneously, HCO+ and 12CO (J=2-1) using IRAM 30m telescope, in order to study the excitation of molecular gas by a fast shock. We detected a broad wing in all CS lines as well as in HCO+, which are as broad as that of the only other clear example of molecular shock in IC443. With our map of the CS line ratio, we will present if there are pre-existing dense condensations in the pre-shock cloud, which survive the initial blast wave and evaporate inside the remnant, and if it can explain the center-filled X-ray emission.

5.04

ASCA Observations of MSH15-56

Paul Plucinsky (Smithsonian Astrophysical Observatory)

We present ASCA observations of the SNR MSH15-56. MSH15-56 is an example of a remnant which defies classification schemes; it is a "composite" SNR in the radio and has a complex X-ray morphology consisting of a partial shell and a bright, central enhancement. The remnant has the classic composite morphology in the radio consisting of a compact central region with a non-thermal spectrum with alpha= -0.1 and an outer shell, also with a non-thermal spectrum but with a significantly steeper spectrum, alpha = -0.4. The X-ray enhancements are not spatially coincident with the central radio enhancement; but they curiously lie on either side of the radio enhancement. The ASCA data show that the X-ray emission from the central region is completely thermal, while the emission from the SW shell is a mixture of thermal and non-thermal components, with the non-thermal component accounting for about 20 GIS spectrum from the central region is well-fitted by an equilibrium, Raymond-Smith model with solar abundances and the spectrum from the SW shell is well-fitted by an equilibrium, Raymond-Smith and a power-law model. There is some evidence for an overabundance of Si in the central region. We will discuss possible explanations for the existence of the non-thermal component in the SW shell and also compare the ASCA data with the ROSAT data to better determine the overall structure and evolutionary state of the remnant.

5.05

Study of the Composite Remnant MSH 11-62

Harrus (Harvard-Smithsonian Center for Astrophysics), Dr. John Hughes (Rutgers U.), Dr. Patrick Slane (Harvard-Smithsonian Center for Astrophysics)

We present an analysis of the X-ray data collected during an observation of the supernova remnant (SNR) MSH 11-62 by the *Advanced Satellite for Cosmology and Astrophysics* (ASCA). We show that MSH 11-62 is a composite